CFWEP Lesson Plan: World Water Monitoring Day Lesson 1: Introduction

Teachers Resource Guide

Page 1: Key Definitions
Page 2: Supporting Definitions
Page 4: Optional Supporting Definitions
Page 5: Guide to Teacher Input

For support, equipment and additional information, contact the **Clark Fork Watershed Education Program (CFWEP)**
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Key Definitions:

pH Scale: The measure of the *acidity* or *alkalinity* of a solution. It is formally a measure of the activity of dissolved hydrogen *ions* (H^+). In solution, hydrogen ions occur as a number of *cations* including hydronium ions (H_3O^+). In pure water at 25 °C, the concentration of H^+ equals the concentration of hydroxide ions (OH^-). This is defined as "neutral" and corresponds to a pH level of 7.0. Solutions in which the concentration of H^+ exceeds that of OH^- have a pH value lower than 7.0 and are known as *acids*. Solutions in which OH^- exceeds H^+ have a pH value greater than 7.0 and are known as *bases* (or alkaline solutions). pH is used as a *water quality indicator*. The typical pH of Montana streams and rivers is about 7-9.

Turbidity: The cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom container if a liquid sample is left to stand (the settleable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated. These small solid particles cause the liquid to appear turbid. Turbidity is used as a *water quality indicator*. Turbidity is measured in "NTU" (Nephelometric Turbidity Units). Water that looks clear in a glass of water will usually have NTU < 2. Water that looks cloudy will have NTU between 2 and 10. Water with NTU > 10 is very muddy.

Dissolved Oxygen (DO): A relative measure of the amount of oxygen that is dissolved or carried in a given medium. It can be measured with a dissolved oxygen probe such as an oxygen sensor in liquid media, usually water. In aquatic environments, oxygen saturation is a relative measure of the amount of oxygen (O_2) dissolved in the water. Dissolved oxygen is measured in standard solution units such as milliliters O_2 per liter (ml/L), or milligrams O_2 per liter (mg/L, also referred to as parts per million or ppm). Dissolved oxygen is used as a *water quality indicator*. The typical DO of Montana streams and rivers is about 6-10 mg/L. Lower DO values can harm trout populations. DO levels lower than this range could also be an indicator of pollution (for example, sewage effluent, or too many nutrients in a stream that cause algae to grow too fast).

Acid: An acid is traditionally considered any chemical compound that, when dissolved in water, gives a solution with a hydrogen ion activity greater than in pure water, i.e. a *pH* less than 7.0. Put another way, an acid is a compound which donates a hydrogen *ion* (H^+) to another compound (called a *base*). Common examples include acetic acid (in vinegar) and sulfuric acid (used in car batteries).

Base: In chemistry, a base is commonly thought of as any chemical compound that, when dissolved in water, gives a solution with a *pH* higher than 7.0. Examples of simple bases are sodium hydroxide (baking soda) and ammonia. Bases can be thought of as the chemical opposite of *acids*. A reaction between an acid and base is called neutralization. Bases and acids are seen as opposites because the effect of an acid is to increase the hydronium ion (H_3O^+) concentration in water, whereas bases reduce this concentration. Bases react with acids to produce water and salts (or their *solutions*).

Watershed: Also called a drainage basin, a watershed is an area of land where water from rain or snow melt drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea or ocean.

The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from adjacent basins by a drainage divide. The drainage basin acts like a funnel, collecting all the water within the area covered by the basin and channeling it into a waterway. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain, which is known as a water divide. Other terms that are used to describe a watershed are catchment, catchment area, catchment basin, drainage area, river basin, and water basin. Watersheds drain into other watersheds in a hierarchical form, larger ones breaking into smaller ones or sub-watersheds with the topography determining where the water flows.

Tailings: The materials left over after the process of separating the valuable fraction from the undesirable fraction of an ore. In the case of the Clark Fork Basin, tailings can lead to Acid Mine Drainage.

Supporting Definitions:

The instructor should note that *water temperature* is also an important parameter to measure in determining water quality. In Montana streams, trout and other aquatic species become stressed at water temperatures above 20°C (or about 68°F). Gases are less soluble in water at higher temperatures, leading to lower dissolved oxygen concentrations in warmer waters. Algae also grows faster in warm water.

Point Source: A point source of pollution is a single identifiable localized source of air, water, or other form of pollution. The sources are called point sources because in mathematical modeling, they can be approximated as a mathematical point to simplify analysis. Examples include water pollution from an oil refinery wastewater discharge outlet, or air pollution from the Anaconda smelter stack.

Nonpoint Source: Nonpoint source (NPS) pollution is water pollution affecting a water body from diffuse sources, rather than a point source which discharges to a water body at a single location. NPS may derive from many different sources with no specific solution to rectify the problem, making it difficult to regulate. According to the U.S. Environmental Protection Agency (EPA), nonpoint source pollution is the leading cause of water pollution in the United States today, with polluted runoff from agriculture the primary cause. Other significant sources of runoff include hydrological and habitat modification and stormwater runoff. Another important cause of NPS pollution is urban runoff of items like oil, fertilizers, and lawn chemicals. As rainfall or snowmelt moves over and through the ground, it picks up and carries away natural and human-made pollutants. These pollutants are eventually deposited into bodies of water.

Total Maximum Daily Load (TMDL): TMDL is a regulatory term in the U.S. Clean Water Act (CWA), describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. This process incorporates both point source and nonpoint source pollutants within a watershed.

Riparian: A riparian zone or riparian area is the interface between land and a stream. Riparian zones are significant in ecology, environmental management, and civil engineering because of their role in soil conservation, their biodiversity, and the influence they have on aquatic ecosystems.

Water Cycle: The Earth's water is always in movement, and the water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states among liquid, vapor, and ice at various places in the water cycle, with these processes happening in the blink of an eye and over millions of years.

Solution: In chemistry, a solution is a homogeneous mixture composed of two or more substances. In such a mixture, a *solute* is dissolved in another substance, known as a *solvent*. A common example is a solid, such as salt or sugar, dissolved in water, a liquid. Solutions should be distinguished from non-homogeneous mixtures such as *colloids* and suspensions.

Ion: An atom or molecule which has lost or gained one or more valence electrons, giving it a positive or negative electrical charge. A negatively charged ion, which has more electrons in its electron shells than it has protons in its nuclei, is known as an *anion*. Conversely, a positively-charged ion, which has fewer electrons than protons, is known as a *cation*. Ions are denoted in the same way as electrically neutral atoms and molecules except for the presence of a superscript indicating the sign of the net electric charge and the number of electrons lost or gained, if more than one. For example: H^+ and SO_4^{2-}.

Colloid: A type of mixture where one substance is dispersed evenly throughout another. Because of this dispersal, some colloids have the appearance of *solutions*. Many familiar substances are colloids, such as fog, clouds, smoke, whip cream, milk, and paint.

Acid Mine Drainage: Acid mine drainage (AMD), or acid rock drainage (ARD), refers to the outflow of acidic water, typically from abandoned metal mines or coal mines. However, other areas where the earth has been disturbed (e.g. construction sites, subdivisions, transportation corridors, etc.) may also contribute acid rock drainage to the environment. Acid rock drainage occurs naturally within some environments as part of the rock weathering process but is exacerbated by large-scale earth disturbances characteristic of mining and other large construction activities, usually within rocks containing an abundance of sulfide minerals (such as pyrite).

Although a host of chemical processes contribute to AMD, pyrite oxidation is by far the greatest contributor. A general equation for this process is:

$$2FeS_2(s) + 7O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4SO_4^{2-}(aq) + 4H^+(aq)$$

The oxidation of the sulfide to sulfate solubilizes the ferrous iron (iron(II)), which is subsequently oxidized to ferric iron (iron(III)):

$$4Fe^{2+}(aq) + O_2(g) + 4H^+(aq) \rightarrow 4Fe^{3+}(aq) + 2H_2O(l)$$

Either of these reactions can occur spontaneously or can be catalyzed by microorganisms that derive energy from the oxidation reaction. The ferric irons produced can also oxidize additional pyrite:

$$FeS_2(s) + 14Fe^{3+}(aq) + 8H_2O(l) \rightarrow 15Fe^{2+}(aq) + 2SO_4^{2-}(aq) + 16H^+(aq)$$

The net effect of these reactions is to release H^+, which lowers the pH and maintains the solubility of the ferric ion.

Put more simply: Pyrite + water + oxygen $\Rightarrow$ iron-rich water + acid

Optional Supporting Definitions:

Conductivity: Electrical conductivity or specific conductivity is a measure of a material's ability to conduct an electric current. The conductivity of a solution of water is highly dependent on its concentration of dissolved salts and sometimes other chemical species which tend to ionize in the solution. Electrical conductivity of water samples is used as an indicator of how salt-free or impurity-free the sample is; the purer the water, the lower the conductivity. Pure, deionized water containing no dissolved solids is a poor conductor of electricity. Conductivity is used as a *water quality indicator*. Conductivity is measured in units called microSiemans per centimeters (µS/l); the typical Conductivity of Montana streams and rivers is about 50-500 µS/l. Polluted fresh water typically has a conductivity above this range. Note that high conductivity does not necessarily indicate pollution; sea water has a conductivity of about 40,000.

Copper: The chief ore mined in Butte, copper (an element) is a contaminant of concern in the Upper Clark Fork Basin. Too much copper in water has been found to damage marine life. The observed effect of these higher concentrations on fish and other creatures is damage to gills, liver, kidneys, and the nervous system. It also interferes with the sense of smell in fish, thus preventing them from choosing good mates or finding their way to mating areas. Copper concentrations as low as 20 parts per billion (ppb or micrograms per liter) can severely impair the health of fisheries.

Arsenic: A contaminant of concern in the Upper Clark Fork Basin, arsenic (an element) is a metalloid, one of a few elements with intermediate properties between a metal and a nonmetal. A notorious poison, arsenic can cause serious human health effects, and arsenic is also recognized as a carcinogen.

Colorimeter: A device that measures the absorbance of particular wavelengths of light by a specific solution. Colorimeters are most commonly used to determine the concentration of a known solute in a given solution.

Guide to Teacher Input:

Lesson Plan Procedure – Teacher Input – Step 4:

Some important factors affecting water quality in western Montana, divided into point source and nonpoint source factors, are listed below. The teacher should first ask students to describe and discuss any factors affecting water quality in western Montana on their own, then describe at least 2-3 of the factors listed below to students. For more information on any of these issues, visit www.cfwep.org and navigate to the "News" or "Resources" pages, or simply do a web search.

Point Source

- *Sewage Discharge:* Sewage discharge can load nutrients into streams, which can potentially reduce the water's oxygen content and increase the growth rate of algae. Sewage discharge from Butte is currently the biggest culprit in impairing the water quality of Silver Bow Creek, although there has been some local discussion about upgrading the sewage treatment plant to discharge cleaner water.
- *Contaminated mine tailings in the Milltown Reservoir:* Historic mine tailings from Butte and Anaconda washed down the Clark Fork River to the Milltown Dam, primarily in a massive 1908 flood. About 6.6 million cubic yards of contaminated tailings sediment backed up in the reservoir. The current dam removal project is excavating about 2.6 million cubic yards and transporting the tailings to the BP/Arco Waste Repository near the town of Opportunity, the former tailings pond for the Anaconda Smelter. The river flush that has resulted from the removal of the dam has increased levels of tailings contaminants (arsenic, heavy metals like copper and lead) downstream at least as far as Thompson Falls.

Nonpoint Source

- *Tailings and waste rock from Butte and Anaconda:* Most waste rock and tailings on the Butte Hill have been capped with 18 inches of clean topsoil; similar caps have also been used in Anaconda. The caps are designed to prevent erosion, and to prevent runoff from rain or snow melt from coming into contact with tailings, which leads to Acid Mine Drainage. There is some evidence to suggest that these old mine dumps are still leading to heavy metal contamination in Silver Bow Creek and in groundwater, although to a much lesser extent than in the past.
- *Historic air pollution from smelting in Anaconda:* The Anaconda smelter discharged smoke rich in arsenic and heavy metals that settled across the Deer Lodge Valley.
- *Development and construction in floodplains:* Development and construction near waterways can lead to streambank erosion and increase the amount of sediment in streams and rivers; increased human activity can lead to contaminated urban runoff (fertilizer, oil, herbicides, pesticides, etc). Agricultural activity (ranching and farming) can similarly impact waterways.
- *Urban areas:* Fertilizer, oil, herbicides, pesticides, and other chemicals used by humans can reach rivers and streams via rain or snow melt if not properly disposed of. Roads and construction can also increase erosion and the amount of sediment in streams and rivers.
- *Drought:* The recent drought can severely impact waterways. Low flows in rivers lead to high water temperatures and lower oxygen, which can harm aquatic life.

Lesson Plan Procedure – Teacher Input – Step 6 and *Optional* Step 7:

Typical water quality parameters for healthy Montana streams and rivers:

- pH: The typical pH of Montana streams and rivers is about 7-9.
- Turbidity: Water that looks clear in a glass of water will usually have NTU < 2. Water that looks cloudy will have NTU between 2 and 10. Water with NTU > 10 is very muddy. Turbidity in Montana streams varies highly with season (i.e. spring runoff typically increases turbidity).
- Dissolved Oxygen: The typical DO of Montana streams and rivers is about 6-10 mg/L. Lower DO values can harm trout populations. DO varies highly with temperature, season, and time of day.
- Water Temperature: In Montana streams, trout and other aquatic species become stressed at water temperatures above 20°C (or about 68°F). Of course, water temperature is also highly variable depending on time of day and season.

- *Optional* – Conductivity: The typical Conductivity of Montana streams and rivers is about 50-500 µS/l. Polluted fresh water typically has a conductivity above this range. Note that high conductivity does not necessarily indicate pollution; sea water has a conductivity of about 40,000.

Optional - **Lesson Plan Procedure – Teacher Input – Step 8:**
Using the 2007 WWMD Year in Review Report (or any current WWMD Year in Review Report), write average water quality values listed in the report for Montana on the board, along with the average values for 1-2 other locations. In a classroom discussion, ask students to develop hypotheses to explain observed differences in average values.
Some possible hypotheses: Differences in local climates (e.g. tropical vs. artic climates); differences in population densities; different local or regional environmental laws or practices; different levels of development.

Lesson Plan Procedure – Teacher Input – Steps 12 and *Optional* Step 14:
Multimeters and Water Test Kits are relatively easy to use, and instructions are included. Instructions are also included with the Colorimeter, which is slightly more complicated than the Multimeters or Test Kits; we will only use the Colorimeter to measure copper concentrations by following the steps in the instructions. Necessary reagents are provided. *If you require additional training in the use of Multimeters, Test Kits, or the Colorimeter, please contact the CFWEP (see contact info on page 1).*

Lesson Plan Procedure – Teacher Input – Steps 16:
Refer back to the issues discussed in Step 4 (above).